

# THE PALEOSURFACE ON THE PASO DEL SAPO VOLCANIC ROCKS, CHUBUT, ARGENTINA

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**ABSTRACT** – The Deseado and Somon-Cura (or Northern Patagonian) massifs in Patagonia are composed of basement exposed rocks and they are situated in Patagonia, one of the largest siliceous provinces in the world, with a volume of 235,000 km<sup>3</sup>, according to Pankhurst et al. (1995). This Middle Jurassic volcanism has an age of 43 Ma; its age decreases regularly from ENE to WSW along Patagonia. These volcanic episodes preceded the opening of the Atlantic Ocean and they correspond to a wide extensional province covering a continental, intraplate region. Most of the Mesozoic topographic features in both massifs are related to Jurassic volcanism and a NE fracture system. From Jurassic times to the late Cretaceous, the ignimbrite plateau and the stratovolcanoes of the Patagonian Mesozoic belt have been exposed to an erosion process bringing the massif levelled surfaces to a planation surface. The late Cretaceous sediments consist of a thin, scattered unit which is distributed on the planation surfaces in the Somon-Cura Massif. A remnant of this buried planation surface can be observed between Paso del Sapo and Piedra Parada, along the Río Chubut valley. A belt of stratovolcanoes from the Middle Jurassic (represented by the Alvar Fm.), consisting on lavas, autobreccias and andesitic dykes, was eroded to a sub horizontal flat, preserving a mantle of regolith which is the product of the underlying vulcanite alteration and it is overlain by quartz sandstones of the Upper Cretaceous Paso del Sapo Fm. This stratigraphic relationship limits the age of the planation surfaces to Late Mesozoic times. Thus, this planation surface can be correlated with the Gondwanic planation surface of Lester C. King. Early Tertiary plate tectonics produced the exhumation of the planation surfaces buried under their own regolith, reactivating erosion surfaces and small basins.

**Keywords:** Patagonian massifs, Jurassic volcanic activity, erosion process, planation surface.

**RESUMEN** – E.Y. Aguilera, E. Aragón, S. Carretero - *La paleosuperficie en rocas volcánicas en El Paso Del Sapo Chubut, Argentina*. Los macizos del Deseado y Somon-Cura (o Nordpatagónico) de Patagonia son cuerpos aflorantes de rocas del basamento y una de las provincias más grandes silíceas en el mundo, con un volumen de 235.000 km<sup>3</sup>, de acuerdo con Pankhurst et al. (1995). Este vulcanismo de edad Jurásica media tiene 43 Ma, y la edad disminuye regularmente desde ENE al WSW a lo largo de la Patagonia. Estos episodios volcánicos precedieron a la apertura del Océano Atlántico y corresponde a una provincia extensional que cubren una amplia región continental de intraplaca. La mayoría de las características topográficas del Mesozoico en ambos macizos están relacionados con el vulcanismo Jurásico y un sistema de fracturas NE. Desde el Jurásico al Cretácico tardío, el plateau ignimbrítico y los estratovolcanes del vulcanismo patagónico del mesozoico han estado expuestos a un proceso erosional que llevan a un nivel la superficies de los macizos a una superficie de planación. Los sedimentos del Cretácico tardío consisten en una delgada y dispersa distribución sobre esta superficie de planación en el macizo de Somon-Cura. Un remanente de esta superficie de planación sepultada se puede observar entre Paso del Sapo y Piedra Parada, a lo largo del valle del río Chubut. Un cinturón de estratovolcanes del Jurásico Medio (representado por la Fm. Alvar), integrada por lavas, autobreccias y diques andesíticos, se erosiona a una superficie subhorizontal plana, en la que se conserva un manto de regolito producto de la alteración de la vulcanita subyacente y lasobreyacen en discordancia las areniscas cuarzosas de la formación Paso del Sapo del Cretácico superior. Esta relación estratigráfica restringe la edad de la superficie de planacion (Ollier, 1992) a los tiempos mesozoicos tardíos. Así, a esta superficie de planación se la puede correlacionar con la superficie de planación gondwánica de Lester C. King (1967). La tectónica del Terciario temprano produce la exhumación de la superficie de planación sepultada en su propio regolito, reactivando superficies de erosión y las pequeñas cuencas.

**Palabras clave:** Macizo Patagónico, actividad volcánica jurásica, procesos erosivos, superficie de planación.

## INTRODUCTION

In Late Jurassic to Late Cretaceous times, the ignimbrite and the Mesozoic Patagonian stratovolcanoes have been subjected to extended periods of weathering, whose effects are imprinted on the bedrock through a

mantle of alteration. Weathering is one of the most important factors involved in the relief degradation. This work is focused on the study of a volcanic unit that has developed an alteration mantle in ancient geological periods with the development of a planation surface (Aragón et al., 2005). Through this evidence it is possible to infer the geomorphological evolution by paleogeographic and paleoclimatic reconstructions in the study area. While these units have been the subject of numerous studies related to petrology, tectonics, structure and stratigraphy, they have rarely been analyzed in terms of their landforms and geomorphological evolution.

Authors like Cravero & Domínguez (1992) provided evidence of a weathering palaeosurface linked to the genesis of kaolin deposits in the Barresian-Aptian (Early Cretaceous) in Argentine Patagonia. In the case of the Alvar Andesites, Aragón et al. (2005) identified these planation surfaces, attributing their genesis as a process based on deep weathering (polygenic model). More recently, Aguilera (2006) identified a large area of regional planation surfaces in Río Negro province, central Northern Patagonia. Ruiz (2006) referred to this geological formation in terms of the pediment surface (developed by erosion of the mountain front related to the edge of the basin) and / or generation of

a large valley associated with the Traquetrén fault trace.

From the viewpoint of geomorphologic theories, the peneplain term - in the sense of Davis (1899, 1909) – emerged as surfaces called *Peniplains*, taken as the result of fluvial erosion in humid surfaces, and *Pediplain* for the extension of pediments in arid areas (King, 1949, 1950, 1953). From a detailed study of these genetic terms and their implications, it is concluded that peneplains are very far from being perfect flat surfaces, but instead, they are low-relief rolling plains (Vidal Romani & Twidale, 1998). Twidale (1983) argued that the peneplains continue being gradually degraded and they are called “*ultillanuras*” (ultiplains). The transformation is very slow and therefore it enables the survival of ancient forms into the current modelling (Twidale, 1976). Some authors consider that the pediments and pedi plains are not genetic or temporary peneplains. They are simply parts of a large set called the planation surfaces (Vidal Romani & Twidale, 1998). It is also possible to recognize plains or areas exhumed by denudation of geological formations that fossilize the erosion surfaces. When the alteration material is being eroded by fluvial action, the weathering front appears like an etched surface known as etchplain (Wayland, 1934), which is referred by other researchers as a chemical corrosion plain (Vidal Romani & Twidale, 1998).

## GEOLOGICAL SETTING

The Patagonian Jurassic volcanic rocks have been studied and recognized with great interest, among other reasons due to the great areal extension that covers around 1 million km<sup>2</sup>. Compositional differences in these volcanic rocks have been observed by different researchers. In the Eastern sector of the Northern Patagonian massif (the Marifil Fm., Malvicini and Llambías, 1972) and the Deseado Massif (Bahía Laura Group, Lesta & Ferello, 1972) the composition of the volcanic units is acidic, while the intermediate to basic volcanic rocks are concentrated in the central part of the Patagonian provinces of Chubut and Río Negro

where the best-known units are the Lonco Trapial Group (Lesta & Ferello, 1972) and the Taquetrén Formation (Nullo and Proserpio, 1975), in which the Alvar Andesites (Aragón & Mazzoni, 1997) are included and whose lithology is composed by andesites and trachytes flows and breccias. This Middle Jurassic age volcanism precedes the Atlantic Ocean opening and corresponds to a wide extensional province covering a continental intraplate region.

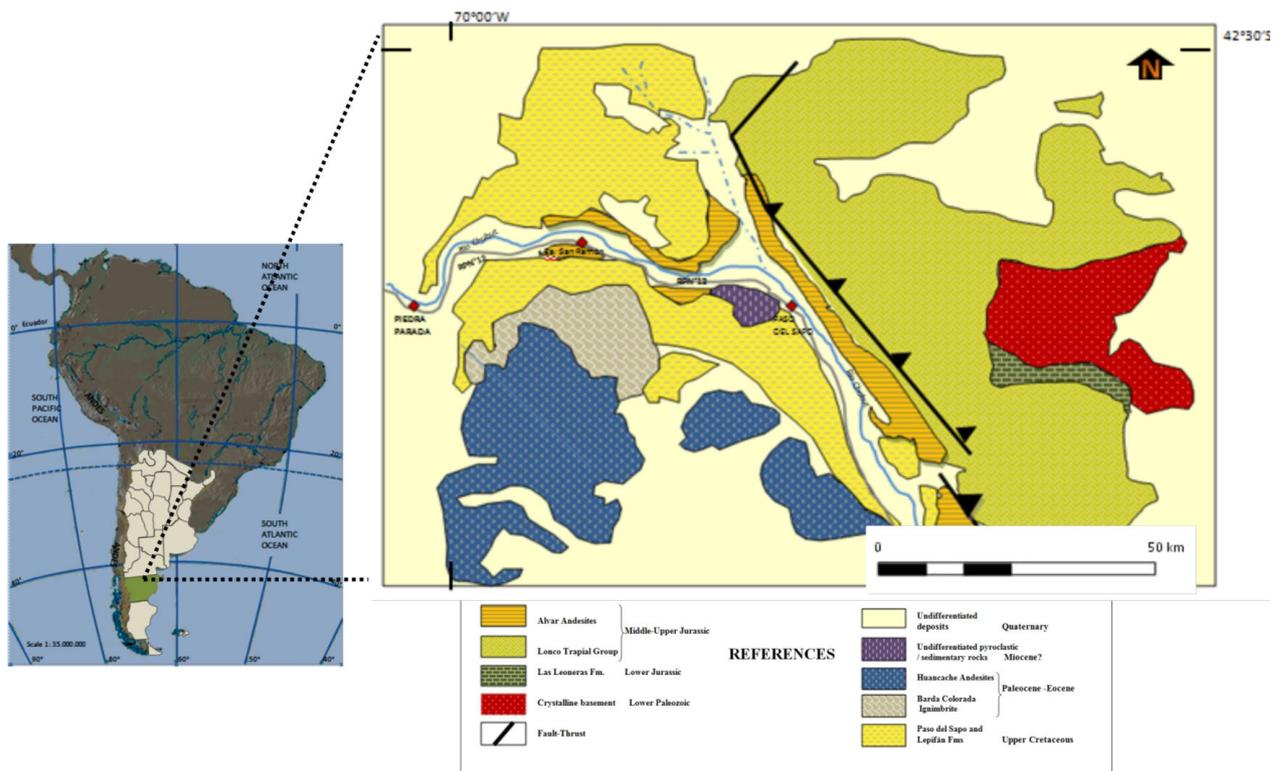
Most Mesozoic topographic features in both massifs are related to the development of the Jurassic volcanic activity and a system of NE fractures.

## STUDY AREA

The study area is located in the province of Chubut, Patagonia, Argentina, between the Paso del Sapo and Piedra Parada localities, in the Río Chubut valley between latitudes 42° 30'00 and 42° 45'00 South and longitudes 70° 00'00" and 70° 45'00" West, respectively (Figure 1).

The relief corresponds to the typical extra-Andean Patagonian landscape, characterized by extended and arid, step-like tablelands. The climate is cold and dry, with short summers and endless winters. However,

summers are temperate and winters are not excessively rigorous. The dominant climate is cold-arid. The air masses coming from the South Pacific Anticyclone climb up the Andean Cordillera and discharge their moisture in both slopes, and then they suffer an adiabatic warming and originate strong and dry winds which are typical of the Patagonian tablelands. Mean annual temperature is 6 °C. Annual rainfall is scarce, oscillating between 100-200 mm/yr. The vegetation corresponds to the steppe type, with two strata: the shrubs, with



**FIGURE 1.** Regional location map and simplified geological map showing the distribution of the different geological units and its associated stratigraphy.

species such as “neneo”, “jarilla” and “malaspina”, and the herbs, in which hard grasses dominate. Along the higher tablelands, the shrubby stratum disappears.

The Río Chubut crosses the Patagonian tablelands from West to East, with a whole basin larger than 50,000 km<sup>2</sup>, with a very swinging stream bed. At Piedra Parada, 19 km before joining the Río Gualjaina, it has a

stream bed up to 80 m wide. It flows eastwards, merging with the Horqueta and de la Buitrera wadis. Its discharge depends upon the available rainfall at its sources and it shows irregular flash floods in the fall and winter. It reaches the Florentino Ameghino dam and from there, it continues until its mouth in the Atlantic Ocean.

## MATERIALS AND METHODS

The interpretation and study of the landscape were carried out by means of aerial photography analysis, field surveys, surveying, geological mapping, topography digitalization, and a digital elevation model based upon

satellite imagery data.

The petrographic analysis of thin sections of the samples taken in the vicinity of the Estancia San Ramón was completed.

## RESULTS AND DISCUSSION

A remnant of an ancient paleosurface has been recognized between the localities of Paso del Sapo and Piedra Parada, in the middle Río Chubut valley, developed upon the Alvar Andesites (Aragón & Mazzoni, 1997). A variety of climate processes that were active from the Middle Jurassic to the Late Cretaceous took part in the relief general degradation of stratovolcanoes, with a resulting planation surface.

On both sides of the Río Chubut, the relationship between the surface in the Alvar Andesites and the

overlying Cretaceous sedimentation may be observed. The almost horizontal nature of the paleosurface is seen along the entire extent of the outcrop, which increases in thickness eastwards. The base of the unit (the Alvar Andesites) is not exposed, because it is covered by the Quaternary fluvial deposits formed by the Río Chubut. The top of the sequence is a sub-horizontal regionally-stretched surface with gentle slopes that can be interpreted as a planation area, which was carved prior to the deposition of the sandstones of the Paso del Sapo

Formation, unconformably lying on top of it. A grayish blue regolith, with purple portions, has been developed on the volcanic rocks. The regolith texture is 1 m thick, clast-supported, with angular clasts of volcanic rocks and scarce sandstone epiclastic matrix (Picture 1).

The Cretaceous sedimentation in the area has fossilized the paleosurface, together with its own regolith. This paleosurface is presently being exhumed by gradual erosion (Picture 2). No absolute dating methods have been used so far to date the paleosurface. A relative age was estimated based on the radiometric age of the Alvar Andesites (Middle Jurassic,  $161 \pm 7.3$  Ma), and of the Paso del Sapo and Lepifán Formations that have buried the paleosurface (Late Cretaceous). In such a period between both units, there was time enough to develop a regolith, of which a thickness of about 1 m has been still preserved. In the sectors where the Cretaceous formations are observed, the regolith is present whereas where the

sedimentary cover is absent the regolith has been mobilized and eroded away.

The paleosurface geomorphology is also linked to a topography inherited from the basement structures. Over this topography, which is also a regional planation surface, the topography of the Alvar Andesites fits to integrate the same topographical surface, which was cited for the Lipetrén area and time-correlated with units like the Mamil Choique Formation (Late Paleozoic granitoids) and the Taquetrén Formation (Jurassic volcanic rocks) (Aguilera, 2006).

The planation process developed upon the Alvar Andesites can be observed at the regional scale where smooth surfaces with few weakened spots generated rounded forms (which are known as “whale backs”) as the main landforms. In a detailed scale, sheets and flakes break off the surface, and grooves and boulders can be seen. In some areas the continuity of the surface is interrupted, with scattered outcrops, more resistant to



**PICTURE 1.** General view of the sequence of purple volcanic rocks of the Alvar Andesites, with no exposed base. The sedimentary rocks of the Paso del Sapo Fm. are unconformably lying on them.



**PICTURE 2.** Regional view of the planation surface in the Río Chubut valley, near Estancia San Ramón.

erosion, are found in the shape of ridges that form small pins to the back of a whale (Pictures 3 and 4).

Locally, small stream valleys have cut the paleolandscape

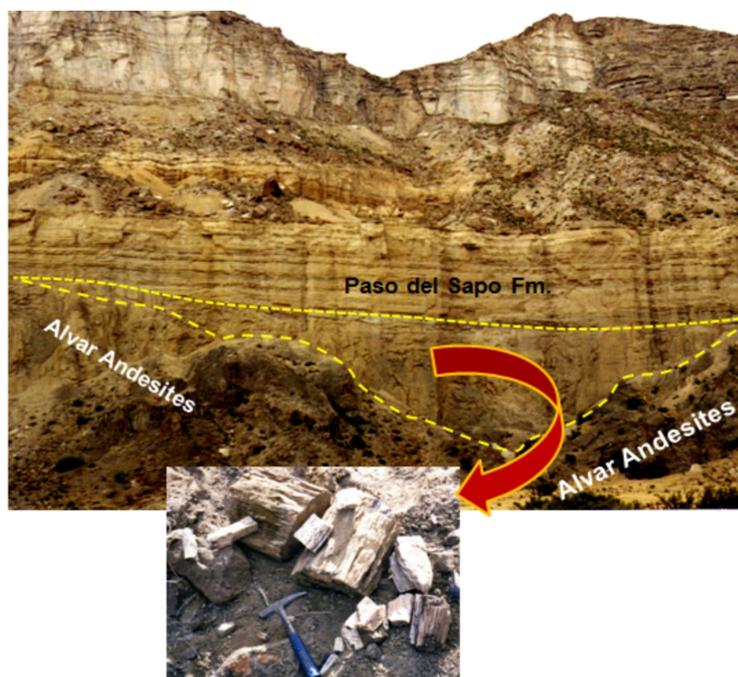
surface and are filled with lens-like sandstones, which include remains of charred stems and leaves and silicified trunks (Aragón et al., 2000) (Picture 5).



**PICTURE 3.** General view of part of the area in which the broken line indicates the reconstruction of remnants of the planation surface and the surviving inselbergs, developed upon the Jurassic volcanics. At the background, Cretaceous sediments.



**PICTURE 4.** Hypothetical reconstruction of the planation surface landscape, with the remaining inselbergs, as it was before the deposition of the Cretaceous sediments, which have been removed from this picture. The broken line represents the position of the ancient planation surface, before partial denudation.



**PICTURE 5.** Small stream valleys have cut the palaeolandscape surface and are filled by lenses like sandstones, which include remains of charred stems and silicified trunks. The horizontal position of the Cretaceous sediments that were deposited on top of the paleosurface may be easily observed.

The development of surface denudation (by flaking) and differential weathering of bedrock structural characteristics has allowed the preservation of more resistant areas in the shape of residual hills (inselbergs) that are landscape benchmarks as erosion exposed them.

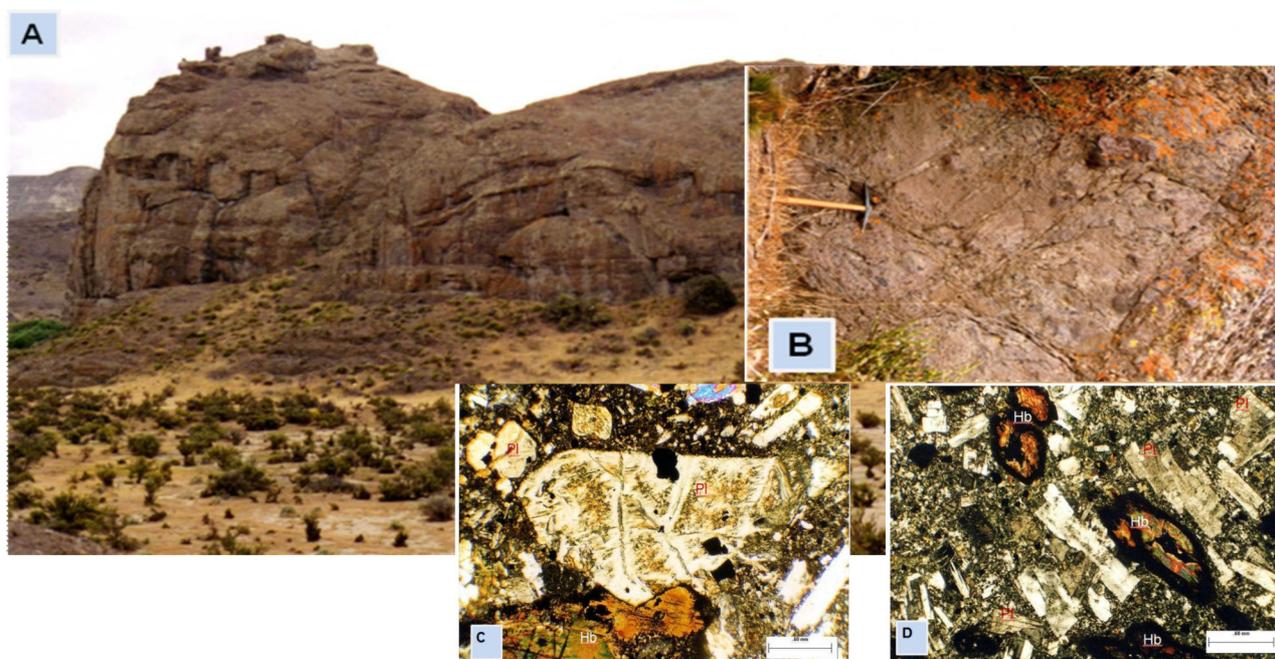
The development of these morphologies seems to be directly linked to the geology of the igneous body. These extrusive volcanic units, whose primary structures are developed in an exogenous environment, are not structurally homogeneous, as they are composed of lavas and breccias, which usually expose differential resistance to weathering and/or erosion.

The lava flows determine horizontal layout structures, forming overlapping lava stacks marking planes of structural weakness between them, which becomes a favorable area for solution percolation, opening chemical attack routes, and adding a series of

contraction/distention fractures resulting from the cooling of the flows.

Through these discontinuity surfaces the meteoric fluids responsible for the alteration of the rock mass penetrate. Semicircular /concentric structures are occasionally seen showing waste materials in transit to the lower portions where the rock is still unweathered. As weathering makes progress, the central area of the blocks remains unchanged, showing rounded corners, covered in reddish loose materials, thus achieving a weathering structure known as the spheroidal type. Spheroidal weathering, according to Ollier (1984, 1992), would be linked to migration of chemical elements inside the rock mass (Picture 6).

The flows also present autobrecciation, in which there are rounded fragments agglutinated on the same material that is being exposed to weathering and which



**PICTURE 6.** (A) Convex dome-shaped hill, of the whale's back type, showing their sides shelled. At its base, it can be recognized the horizontal arrangement of the cast that is lost to the roof. With a higher detail, grooves, sheets and flakes that break off the surface can be seen. (B) Decomposition of the volcanic rocks from cooling joints, leading to fragmentation into angular blocks whose boundaries include stretches of peeling or flaking (sheet fractures) where weathering made progress. Photomicrographs are showing (C) rounded phenocrysts of plagioclase (Pl), crossed by transgranular microfractures. High weathering of hematite into clay minerals has taken place.

The plagioclase twins have their edges blurred by alteration. Hornblende phenocrysts (Hb) are highlighted with a significant mobilization of iron oxides from their cleavage planes (crossed nichols) and (D) abundant plagioclase, grouped in glomeruli, shows the strong alteration into clay minerals. The plagioclases have zonal alteration which can be seen starting from their cores. The crystals are troubled by argillaceous alteration. Details of hornblende phenocrysts centers and edges of oxides and opaque minerals can be seen (crossed nichols).

show small fractures, enabling husked forms to generate boulders. Sometimes, the flows are cut by dykes with the same petrographical composition. The presence of dykes involves fractures and subsequent fill forcing the occurrence of another type of differential response to weathering and erosion.

Breccias show a matrix-supported texture, with poorly sorted, angular and rounded clasts of volcanic composition, together with granitic and sedimentary lithoclasts. This varying composition explains the

lithological and structural anisotropy under the action of atmospheric agents. The described landforms belong to a granitic landscape, a broad term which includes rocks of varied nature, but with dominant granite. Vidal Romani & Twidale (1998) have recognized weathering products in volcanic rocks which were formed under hot and humid weather conditions. Although these are not landforms commonly observed in volcanic rocks, the possibility of their occurrence has been mentioned by Vidal Romani & Yepes Temiño (2004).

## CONCLUSIONS

The remnants of an ancient planation surface can be observed between the Paso del Sapo and Piedra Parada localities, along the Río Chubut valley, Patagonia.

Field evidence suggests that the stratovolcanoes relief corresponding to the Alvar Andesites had been exposed for an extended period of time to chemical attack by weathering, due to sub-aerial exposure, when the volcanic rocks underwent a series of transformations and mineral disaggregation that formed an alteration layer (regolith) directly dependent on specific climate conditions and which forced the development of a granitic landscape.

The regolith mantle reveals that the climate processes that were active from the Middle Jurassic to the Late Cretaceous were developed in humid and warm conditions favoring weathering. Field observations also indicate the presence of small stream valleys eroded in the paleosurface. Due to this reason, it is inferred that this area was not perfectly flat but with gentle undulations instead, with irregularities and local depressions where some of the regolith was hosted and remained safe from denudation and mobilization.

The presence of regolith gives an evolutionary record of these weathering processes. The area has been partially buried by Cretaceous sedimentary deposits and subsequently re-exposed as an exhumed surface by denudation. The surfaces resulting from deep weathering with further regolith mobilization have been called “etched surfaces” or “etchplains” (Wayland, 1934). This surface was generated in the Jurassic, perhaps as a consequence of the block uplifting related to the rifting and the South Atlantic Ocean opening mechanism, which coincided with a tectonic global change from compressive to distension regimes. Unconformably overlying this paleosurface, the Late Cretaceous quartzitic sandstones of the Paso del Sapo Formation are found. The calculated radiometric age for the Alvar volcanic rocks is  $161 \pm 7.3$  Ma (Middle Jurassic); the Paso del Sapo Formation has been assigned to the Campanian (Late Cretaceous,

83.5-73.1 Ma). Sub-aerial exposure of the Alvar volcanics was estimated in about 80 Ma, a period long enough for deep weathering processes action and partial denudation of the unit as weathering made progress. The chronology and events that such sub-aerial exposure involves helps to improve the understanding of long-term landscape evolution in its chronological context, accepting that the planation surface persisted with minor changes for very long periods of time.

These stratigraphical relationships restricted the age of the planation surface (Ollier, 1992) to Late Mesozoic times, which allows also that it can be correlated with Lester C. King's (King, 1967) Gondwanic planation surface, suggesting the possibility of drawing a parallel sequence between this area and the geological and climatic history from other regions of the Gondwana super-continent, before rifting that led towards the opening of the South Atlantic Ocean (Rabassa et al., 1998). Early Tertiary plate tectonic produced the exhumation of the planation surfaces which were then buried in their own regolith, reactivating erosion surfaces and small basins. It is worth noting the importance of Cretaceous sedimentation, because it fossilized and preserved the andesites and the regolith as an indisputable evidence of regional deep weathering.

Moreover, where the surface has been exhumed, the horizontal arrangement of the sedimentary strata shows the flat top of the andesites, which acted as the deposition surface for the Cretaceous units.

According to the tectonic features observed this region has been a rigid environment without significant subsidence or folds, which only supports block-faulting and thrust. These conditions are presently maintained together with its anorogenic characteristics.

This contribution represents then a Patagonian example of a planation area developed on volcanic rocks, which were later fossilized together with its own regolith, and later exhumed by Late Cenozoic denudation.

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